IMPROVEMENT OF AIR MOBILITY COMMAND AIRLIFT SCHEDULING

GRADUATE RESEARCH PROJECT

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Abstract

Air Mobility Command provides rapid, global mobility and sustainment for US armed forces and plays a crucial role in humanitarian support operations around the world. Since customer requests for airlift resources to support these missions almost always exceed the supply, effective and efficient scheduling of these resources is critical.

This research explores the similarity between Air Mobility Command airlift scheduling and US motor carrier industry scheduling with respect to improving efficiency. It begins with an overview of Air Mobility Command's organization and functional relationships with regard to scheduling of airlift assets and a review of currently fielded airlift modeling and simulation systems. This is followed by a review of the US motor carrier industry with an emphasis on scheduling and efforts to improve efficiency in that industry as well as the results.

After reviewing practices employed by the motor carrier industry to improve efficiency, similar methodology is applied to a set of historical airlift missions to measure and attempt to improve the scheduled efficiency of these missions. A measure of efficiency, the operating ratio, is developed through analysis of Air Mobility Command mission numbers. Finally, case study analysis is presented of computer simulated scheduling utilizing various optimized scheduling policies.

IMPROVEMENT OF AIR MOBILITY COMMAND AIRLIFT SCHEDULING

Chapter 1 – Introduction

Background

Scope.

With a fleet of aircraft which perform hundreds of operational missions around the world every day, Air Mobility Command has a responsibility to the nation to provide the most efficient use of resources possible. Although the personnel responsible for planning and directing the global air mobility mission at the Tanker/Airlift Control Center strive to balance efficiency and effectiveness, there are resources within other transportation industries which may provide solutions to optimizing our performance. This paper examines the challenges, practices and emerging technology solutions of the US private motor carrier industry for possible application to the scheduling of strategic airlift assets to determine if significant improvements in efficiency can be achieved.

Evolution of Research Topic

The original idea for this research project occurred during an assignment at the Tanker/Airlift Control Center as a Chairman, Joint Chiefs of Staff Exercise/Contingency airlift director from 1997 to 1998. In this position, the author was responsible for planning airlift movements supporting deployment and redeployment of Continental US based forces for large exercises and contingencies utilizing Continental US based airlift aircraft. Since these movements were almost always one way, aircraft were usually flown home empty during the deployment phase and flown out empty during the redeployment phase, resulting in non-productive movement of aircraft. While this inefficiency could possibly be tolerated if we had a surplus of airlift assets, in reality there is much more demand for airlift than Air Mobility Command can provide.

As will be explained later, various directorates within the Tanker/Airlift Control Center essentially compete for airlift resources to support their individual taskings. The directorates are organized by mission type and each plans missions throughout the world. With no formal system in place to share resources, the result was often the movement of empty aircraft when there were passengers and cargo in need of airlift. The frustrating effect of this system for a planner was the frequent loss of committed assets for planned missions just prior to execution due to short-notice higher priority requirements. The solution was often a manual review of tens, if not hundreds, of existing missions belonging to other planners to determine if there were non-productive legs which could be utilized for a different customer. Coincidently, a successful pairing of complimentary movements would result in a savings to both customers through reduced chargeable flying hours supporting their exercise or contingency. After several iterations of this process, results revealed it might be more beneficial to formalize the process of matching complimentary movements and perform it earlier in the planning process. This result indicated a similarity to the challenges faced by the motor carrier industry in scheduling cargo movements throughout the country to minimize non-revenue producing movements of their trucks.

Problem Statement

Because strategic airlift is vital to achieving national objectives and the supply of assets to provide it are expensive and limited, the leadership at Air Mobility Command and the Tanker/Airlift Control Center ensures airlift resources are efficiently employed. This research examines the current practices for scheduling strategic airlift and compares them to private sector transportation scheduling to determine if our efficiency can be improved. In particular, the methods employed by the motor carrier industry are examined to determine if their practices can be employed by Air Mobility Command to provide a significant reduction in non-productive movement of airlift aircraft.

Research Questions

The overarching question is, "Can the scheduling effectiveness of airlift resources be improved by study and adoption of scheduling practices employed by the motor carrier industry?" In order to answer this question, the following investigative questions are employed:

1. How does the Tanker/Airlift Control Center currently schedule airlift movements? Current practices employed by the Tanker/Airlift Control Center Mobility Management division to allocate airlift assets to move cargo and personnel are reviewed.

2. How efficiently are airlift assets scheduled? A method of measuring airlift scheduling efficiency is explored.

3. How does the motor carrier industry schedule cargo movements? Current and evolving methods for efficiently scheduling cargo shipment are examined.

4. Can practices employed by the motor carrier industry be adopted to improve airlift scheduling? Appropriate practices and methodologies are studied for feasible adaptation to the airlift scheduling process.

5. What gain in efficiency could be expected by adoption of these practices? Using the measurement developed in question two; any change in efficiency is identified for further cost/benefit analysis.

Assumptions

In order to limit the complexity of the airlift scheduling process, certain assumptions have been established with regard to this project. With any resource allocation model, one of the major constraints is the supply of resources. Use of a historical mission set should guard against scheduling more airlift resources than are available since any optimized schedule should use fewer resources than were actually committed. This historical mission set is gathered from a time frame so as to avoid a major buildup or drawdown of forces in support of recent large scale contingencies such as Operation Enduring Freedom or Iraqi Freedom. Although large scale movements such as these are certainly part of the Air Mobility Command mission, they are not representative of day to day operations and would probably affect the amount of optimization possible due to concentration of effort in a single geographical area.

Airlift scheduling is a complicated endeavor which must consider a myriad of issues such as load planning, range, fuel availability, crew duty day limits, airfield operating hours and diplomatic clearances. Although the simulations and models employed in this research address these issues with varying degrees of fidelity, they are not central to this research. The scope of this research is only concerned with allocation of resources to fill requirements, and it is assumed these associated planning considerations can be worked out for the optimized schedule. This study is further limited to measuring schedule efficiency.

Air Mobility Command fulfills three main mobility mission types: strategic airlift, tactical airlift and aerial refueling. This research focuses on resource allocation for strategic airlift missions only due to the similarity with the motor carrier industry. The tactical airlift and aerial refueling missions have unique planning requirements which reduce the level of optimization available for exploitation.

Methodology and Organization

In order to address the research problem and answer the investigative questions, Chapter 2 begins with an overview of Air Mobility Command's organization and functional relationships with regard to scheduling of airlift assets and a review of currently fielded airlift modeling and simulation systems. This is followed by a review of the US motor carrier industry with an emphasis on scheduling and efforts to improve efficiency in that industry as well as the results.

Within the framework established by Chapter 2, Chapter 3 delves into the process of determining if opportunity exists to improve scheduling efficiency. This is accomplished by analysis of a collection of historical airlift missions to establish a measure of scheduling efficiency. The load movement requirements represented by these missions are examined to determine if opportunity exists to improve the scheduled efficiency.

Armed with this data, Chapter 4 compares the scheduling efficiency of the historical mission set with the efficiency of the modeling and simulation outputs to determine first if the results are legitimate and then if a significant improvement is possible. Lastly, Chapter 5 presents the results of this comparison along with recommendations for further investigation

Chapter 2 – Literature Review

Air Mobility Command

Overview and Functional Relationships.

Air Mobility Command is a major command of the US Air Force and a transportation component of US Transportation Command. Air Mobility Command is the sole provider of common-user air mobility and aeromedical evacuation to support the deployment, employment, sustainment and redeployment of US forces around the world (JP 4-01, 2003:II-4). Under a recent Air Mobility Command reorganization, the Tanker/Airlift Control Center is the global Air Operations Center for the newly created 18th Air Force and serves as the executive agent which plans, tasks, schedules and provides command and control for all Air Mobility Command directed airlift and tanker missions (AMCI 11-208, 2000:9). The primary Air Mobility Command airlift missions which support external customers are classified according to mission type as Contingency, Exercise, Channel or Special Assignment Airlift Missions and are planned and coordinated by three directorates within the Tanker/Airlift Control Center. Contingency and Exercise mission are planned by Global Readiness, Channel missions are planned by Global Channel Operations and Special Assignment Airlift Missions are planned by Current Operations (AMCI 11-208, 2000:10).

Each directorate receives airlift taskings and requests from various customers according to the type of airlift required. Planners within each directorate then build missions utilizing the appropriate aircraft type generally following the pattern of departure from home station and flight to onload location (positioning leg), flight from onload location to offload location (active leg) and flight from offload location back to home station (depositioning leg). Once the proposed mission is built, the planner presents the mission to the Mobility Management directorate, which manages and allocates the airlift resources available to Air Mobility Command. Based on available aircraft, aircrews and the priority of the mission, Mobility Management assigns the mission to a particular Airlift Wing or Group or informs the planner the mission is not supportable. Often, missions with higher priority will be allocated resources which were previously committed to other missions.

Contingency and Exercise missions are used to deploy and redeploy military forces in support of contingency and exercise operations. The distinguishing feature of these missions is the movement requirements that are derived from a database known as Time Phased Force Deployment Data (TPFDD) which is discussed in greater detail later. Unless these missions are supporting a swap out for a unit in place at the deployed location, they usually transport personnel and cargo in one direction. Channel missions are primarily used to transport sustainment cargo supporting permanent forward bases or military forces deployed for long-term contingency operations. These missions are usually planned as a round trip from the Continental US to a forward location, allowing cargo and personnel to be transported in both directions. In practice, however, most of the cargo is consumable items which are moved outbound only. Special Assignment Airlift Mission airlift is provided to users with unique or classified cargo, personnel or missions with special needs. Similar to contingency and exercise airlift, the mission usually consists of picking up personnel and cargo from one location and delivering it to another, with the resultant positioning and depositioning of an empty aircraft.

Airlift Simulation and Modeling Programs.

Airlift Simulation and Modeling Overview.

Airlift modeling programs share certain common characteristics of design and historically fall into two general categories. The airlift "problem" modeled is to transport a finite number of passengers and finite amount of cargo from one geographic area to another utilizing a given fleet of aircraft with various characteristics through a network of airbases subject to numerous constraints. In general, movement from one geographic region, such as the Continental US, to another, such as Korea, is considered inter-theater airlift while movement within a geographic region is considered intra-theater airlift. Final delivery of all passengers and cargo is known as closure. Closure is also used to denote delivery of a subset package of passengers and cargo.

The data describing passengers and cargo to be moved for contingency and exercise deployment and redeployments is contained in a database referred to as Time Phased Force Deployment Data. This database provides a listing of all equipment and passengers to be transported along with supporting data to facilitate scheduling including the mode of transportation to be utilized such as surface, sealift or airlift. As the name implies, the TPFDD provides for time phasing of the delivery of forces based on the priority of need in the destination theater. For airlift modeling, only passengers and cargo coded for airlift movement are considered. While a TPFDD may contain several levels of data down to weights and dimensions of individual pieces of equipment, the level normally used for airlift modeling consists of the information in Table 1.

Table 1. TPFDD Data Elements

Data Element	Description
Unit Line Number (ULN)	A unique identification code for a package of equipment and cargo
Aerial Port of Embarkation (APOE),	The airfield scheduled for pickup
Aerial Port of Debarkation (APOD)	The airfield scheduled for delivery
Destination	Final delivery destination
Available to Load Date (ALD),	The date the package can be available for pickup at the APOE
Earliest Arrival Date (EAD)	The earliest date the package can be delivered to the APOD
Latest Arrival Date (LAD)	The latest date the package can be delivered to the APOD
Required Delivery Date (RDD)	The latest date the package can be delivered to the destination
Passengers	The number of passengers in the package
Bulk	The amount of cargo in short tons which can be loaded on 463L pallets and transported on any military or civilian cargo aircraft
Oversize	The amount of cargo in short tons which will not fit on a 463L pallet but can be transported on any military airlift aircraft and some civilian cargo aircraft
Outsize	The amount of cargo in short tons which can only be transported on a C-17 or C-5 aircraft due to its size

As implied by the preceding table, there are two possible scenarios for passengers and cargo to be delivered to their destination. If the aerial port of debarkation and destination are collocated, movement is satisfied by delivery to the aerial port of debarkation. If they are not collocated, final delivery to destination may or may not be coded for airlift by intra-theater airlift. Inter-theater airlift is centrally managed by Air Mobility Command while intra-theater airlift is managed by the theater commander and each theater commander controls a separate fleet of aircraft.

The fleet of aircraft apportioned for the modeling scenario is comprised of several types with various characteristics. Each type can carry a mixture of passengers and one or more of the three classes of cargo and has a specific range/payload tradeoff where the range is inversely related to the total payload carried. Each type flies at a different airspeed, has varying requirements for the amount of time required for enroute refueling stops, onload and offload stops, and is restricted to certain airfields due to weight and runway length available. Contracted civilian aircraft are also utilized with similar variation in capabilities.

The network of airfields available must be modeled with regard to several factors which determine the throughput capability. A figure known as Maximum on Ground is used for this purpose. In its simplest terms, Maximum on Ground is the maximum number of aircraft which can be simultaneously present at a given airfield; however, there are several dimensions to Maximum on Ground. Parking Maximum on Ground is the number of various types of aircraft which will physically fit into the parking area available. Since different types of aircraft require more or less room depending on their size, parking spots are usually designated as wide-body for large aircraft and narrow-body for small aircraft. Generally though, throughput is limited by what is known as working Maximum on Ground. Working Maximum on Ground is the number of aircraft which can reasonably be expected to process through an airfield within standard ground times in consideration of air traffic control, parking area, availability and speed of refueling, availability of aerospace ground equipment , material handling Equipment and ground personnel. Given this number, aircraft can be scheduled to arrive and depart so the maximum is never exceeded.

In addition to these basic considerations, there are constraints which may be included in the model to provide increased fidelity in the output. Some examples include aircrew, weather and maintenance reliability. Although apportionment of aircraft is rather straightforward, a confounding factor is the number of aircrews available to operate those aircraft. Aircrews have specific limits on the amount of time they can fly before they are required to rest for a certain time period. If crews were only available at a one to one ratio to the aircraft, the aircraft would thereby have the same limits. In practice, crews are available at a greater than one to one ratio, but the actual number affects the scheduling of the aircraft. The location of the crews is also important since there must be a replacement crew available where and when the previous crew must enter crew rest, or the aircraft must wait until a crew is available. Usually, one or more strategic locations are chosen as a "crew stage" where aircraft passing through are provided with a fresh crew with enough time available to reach the next stage location. Weather can also impact the airlift operation by causing delays to aircraft enroute, during arrival/departure or causing aircraft to divert to alternate airfields. Finally, maintenance reliability impacts the amount of time an aircraft is available to perform its mission. For all aircraft departures, there is some percentage of departures delayed due to maintenance problems. In addition to the direct impact on movement of a load of cargo, this can have a ripple effect on aircrew availability and Maximum on Ground.

Two basic types of modeling programs are linear programming models and simulations. Linear programming models seek to find an optimal solution to a linear objective function by either minimizing or maximizing some value while honoring the linear constraints placed on resources consumed during the process. In the case of air mobility, this can take the form of minimizing either the number of sorties flown or the number of flight hours, but could also seek to maximize the number of passengers and amount of cargo delivered on time. Typically in this type of model, variable constraints such as weather or maintenance reliability are established as a fixed value based on historical averages. These models are deterministic because they are not probabilistic and always produce the same answer for a given set of inputs. The other type of modeling program, the simulation, takes a different approach. Simulations seek to describe what might reasonably happen in a scenario given a set of inputs and constraints. The primary difference is the handling of these constraints. Rather than apply a fixed number to the variable constraints, simulations assign a random value based on some distribution of possible values derived from historical data. A common example is the normal distribution curve. Because of this randomness in the constraints, each time the simulation is run, it will produce a different outcome. Rather than attempting to predict what will actually happen for a given scenario, a well crafted simulation provides insight into the range of possibilities which could realistically be expected to occur. In practice, the simulation is run several times and the various outcomes compared to one another to formulate a best-case/worst-case description of the possible outcomes.

NPS/RAND Mobility Optimizer

History

The NPS/RAND Mobility Optimizer, as its name implies, is the result of a joint effort between the Naval Post-Graduate School (NPS) and the RAND Corporation. The Naval Post-Graduate School began mobility modeling in 1991 with a project for the Joint Staff's Force Structure Resource and Assessment Directorate which resulted in the Mobility Optimization Model. The Naval Post-Graduate School later combined this model with one from the Air Force Studies and Analyses Agency, THRUPUT, to produce THRUPUT II in 1994-1996. At about the same time, a group at RAND developed a similar model called Concept of Operations. The Concept of Operations model incorporated some details which were missing in THRUPUT II, such as aircrews and aerial refueling, but lacked other abilities, such as tracking ownership of a cargo movement, which were resident in THRUPUT II. In 1996, teams from the Naval Post-Graduate School and RAND jointly developed the NPS/RAND Mobility Optimizer to take advantage of the inherent strengths of both models while overcoming the shortcomings of each (Baker *et al.*, 2002:583).

Programming Methodology

The NPS/RAND Mobility Optimizer was designed as a linear programming model and seeks to minimize the number of passengers and amount of cargo delivered late or not at all. This is accomplished by an objective function which minimizes the sum of weighted penalties assigned for late delivery or non-delivery of each Unit Line Number's passengers and cargo. In addition, secondary terms discourage unwanted behavior such as leaving aircraft in the destination theater. This is accomplished by building combinations of allowable factors of aircraft, cargo, routing and time period and then assigning the apportioned aircraft inventory and crews against the Unit Line Numbers contained in the TPFDD based on the Available to Load Date, Earliest Arrival Date and Latest Arrival Date. This process is repeated until all the movement requirements have been met (Baker *et al.*, 2002:590).

Strengths and Weaknesses

As a linear programming model, the NPS/RAND Mobility Optimizer seeks to find a tractable optimum solution to a set of movement requirements. This makes it well suited for certain tasks, but ill-suited for others. Since the program makes no attempt to model uncertainties such as weather, it produces a best-case scenario in estimating closure which can never be achieved in execution. However, with this limitation in mind, the solutions produced are still useful for estimation. Possibly more important, the deterministic approach of the model makes it especially useful for comparative studies between courses of action, TPFDD construction or aircraft allocation. Although the closure estimates produced are not absolutely applicable to a given scenario, the comparative results are very valid. Similarly, detailed output reports can allow planners to identify bottlenecks in the airlift system such as a single airfield which constrains the total throughput. In fact, the program has been used to study the effects on changes to Air Mobility Command's enroute base structure and the decision to acquire the C-17 versus the B-747.

Another limitation of the NPS/RAND Mobility Optimizer is the somewhat single-minded purpose for which it was developed. The NPS/RAND Mobility Optimizer is, for practical purposes, limited to modeling a single TPFDD movement from one theater to another as in the deployment for Operation Iraqi Freedom. In addition to TPFDD movements, there are Channel and Special Assignment Airlift Missions which must be transported concurrently and utilize the same resources. A related limitation is the modeling of intra-theater airlift. In the NPS/RAND Mobility Optimizer, the same resources are utilized to move cargo from the aerial port of debarkation to final destination. While this may occur in some cases, the normal method of intra-theater delivery is a discreetly scheduled movement generated by the theater airlift planning organization using a separate fleet of aircraft.

Air Mobility Operations Simulator

History

In October 1999, Air Mobility Command contracted with L3 Communications Corporation to develop a new model which would overcome many of the limitations of the NPS/RAND Mobility Optimizer. The first prototype was delivered in August of 2000, with full-scale development commencing in October. The first version contained only inter-theater airlift functionality with progressive enhancements and the addition of air refueling deployment and employment in versions delivered in 2001 and 2002. The next version should be released in April 2004, and it should include intra-theater airlift and enhancements to visualization and user interface tools (Bassham, 2003:1).

Programming Methodology.

The core of the Air Mobility Operations Simulator is composed of five high-level object classes (entities, requirements, resources, command and control, and environment) which interact to produce the desired outcome. Entities, such as airbases and missions, hold and use resources and report their status to command and control. Resources are those things needed to perform tasks such as aircraft, aircrew, material handling equipment or parking spots. Requirements are the elements which drive the tasks assigned by command and control and include but are not limited to the TPFDD. Command and control is the decision-making process which considers requirements and resources and tasks entities to meet the requirements. Finally, environment is the external and uncontrollable factors which affect requirement completion and cause command and control to make adjustments to taskings. As with the NPS/RAND Mobility Optimizer, the program builds feasible combinations of aircraft, aircrew, routes and cargo to satisfy the requirements given, but in much greater detail. Then during the simulated execution, adjustments are made to correct for the environmental impacts (Air Mobility Command, 2000:3).

Strengths and Weaknesses

The Air Mobility Operations Simulator overcomes many of the shortcomings of the NPS/RAND Mobility Optimizer through a much more detailed architecture allowing it to capture many of the real world complexities involved in airlift operations. For example, the Air Mobility Operations Simulator is not limited to a TPFDD movement and can include Channel and Special Assignment Airlift Mission requirements. It also performs discreet modeling of inter-theater and intra-theater scheduling with separate fleets of aircraft. However, it is a simulation model in purpose and does not expressly seek to find an optimum solution to satisfy requirements. It does allow user input in the form of rules to modify how the simulation schedules resources to satisfy requirements.

The Optimizing Simulator

History

The Optimizing Simulator is a concept currently under development in the Department of Operations Research and Financial Engineering at Princeton University. It is an attempt to synthesize the value of optimization and simulation models into a single programming solution.

Programming Methodology.

The Optimizing Simulator implements a methodology known as Dynamic Resource Transformation which models the information content of decisions, allows for complex resource attributes and provides ease of introducing new classes of decisions. The term resources refers to all objects being managed and are divided into resource classes based on resource attributes. Some attributes are static, such as aircraft characteristics, while others are dynamic, such as aircraft location. Resources are combined to form resource layers which can be modeled, such as loading cargo onto an aircraft. Decisions are then made on resource layers to satisfy requirements, such as the decision to move the aircraft to another airfield. These decisions are based on information available before the activity is initiated and can be static as in the NPS/RAND Mobility Optimizer model or dynamic as in the Air Mobility Operations Simulator. The Optimizing Simulator seeks to maximize the total contribution to satisfaction of requirements in an iterative fashion each time a decision point is reached based on the information available at the time. When dynamic information is included, such as the modeling of weather, an initial decision vector to send an aircraft along a predetermined route can be changed to another routing to minimize disruption to requirement satisfaction (Wu *et al.*, 2003:9-20).

Strengths and Weaknesses.

Still in development, the Optimizing Simulator has potential to bridge the gap between optimization and simulation. By controlling the amount of information available to the program from current knowledge to forecasts to impacts of decisions to "expert knowledge", the model can be made to solve the transportation problem in various ways. When given only the set of current knowledge, the Optimizing Simulator can behave much like the NPS/RAND Mobility Optimizer in producing an optimized solution. When forecasts are introduced on external impacts, the program can work like the Air Mobility Operations Simulator to provide simulated outcomes, a technique referred to as Approximate Dynamic Programming. By combining these two types of information, the simulator can optimize the solution over a rolling horizon of future time periods as new information is introduced. Finally, rules can be introduced to simulate expert knowledge to guide the simulation to achieve desired patterns of behavior, such as consideration of whether to send an aircraft to an airfield without maintenance support for that type aircraft balanced against the benefit of using that aircraft type based on a prediction of the need for maintenance during that stopover (Wu *et al*., 2003:27).

The Motor Carrier Industry

Overview.

Prior to World War II, railroads transported most cargo within the continental United States. After World War II, the motor carrier industry began to grow and compete with the railroads, in large part because of the investment by the US in the interstate highway system during President Eisenhower's administration. As the highway system developed, motor carriers were increasingly the mode of choice for shipment of manufactured goods.

> In 1950, the railroad industry moved 1.4 billion tons of freight on an intercity basis, while motor carriers moved 800 million tons. In 1980, railroads moved 1.6 billion tons, compared to 2.0 billion tons by motor carriers. By 1997, intercity motor carriers were handling 3.7 billion tons and 1.05 trillion ton miles, compared with 1.97 billion tons by rail. (Coyle *et al.*, 1999:97)

From 1935 to 1980, the motor carrier industry, like all forms of US transportation, was heavily regulated. During this time, the government viewed the transportation sector as a public utility to be maintained, protected and promoted. With the passage of the Motor Carrier Act in 1935, the motor carriers were placed under the Interstate Commerce Commission and were required to have certificates of authority issued by the Interstate Commerce Commission in order to operate. Under Interstate Commerce Commission regulation, carriers were classified as common, contract, private or exempt and each type operated under specific rules for rates and scheduling. The Interstate Commerce Commission controlled entry and exit of companies into and out of the industry, prescribed the routes over which the carriers could operate and the rates which they could charge for various classes of cargo. Under this system, the rates set by the Interstate Commerce Commission were based on actual costs plus a "fair" profit. In many cases, carriers were only allowed to haul freight in one direction on a particular route and empty backhauls were common. However, since the Interstate Commerce Commission set the rates based on a guaranteed profit, there was little incentive to increase scheduling efficiency (Stock and Lambert, 2001:335-337).

In addition to the regulatory classifications, there are two basic types of service offered by motor carriers: Truckload and less than truckload. Truckload service is provided at reduced rates for shippers who have sufficient volume of freight to efficiently utilize an entire truck from a single pick-up location to a single drop-off location. Less than truckload service is provided to shippers who have smaller shipments. For increased rates, the carrier picks up freight from several shippers and consolidates them into a truckload for movement. The full truck moves the freight to a break-bulk facility where the shipments are broken down and delivered to the individual destinations. This paper concentrates only on truckload carriers because of the similarities to airlift operations where an entire aircraft is usually dedicated to a movement requirement.

Beginning with the Motor Carrier Act of 1980 and culminating in the Interstate Commerce Commission Termination Act of 1995, almost all economic regulation of the motor carrier industry has been removed. Although the classification of carriers still exists, the types are mostly meaningless and all carriers are free to negotiate rates with all shippers (except for household goods). As a result of deregulation, competition has increased dramatically and rates have decreased. During the period from 1980 to 1989, approximately half of the largest carriers in the less than truckload segment of the market declared bankruptcy (Stock and Lambert, 2001:338). The carriers that remain profitable have done so by increasing their productivity and efficiency. One of the innovations that has contributed to this increased efficiency is scheduling optimization.

Examples of Efficiency Improvements.

North American Van Lines.

In 1988, the Commercial Transport Division of North American Van Lines was a truckload carrier with a fleet of 5,800 trailers and annual revenues exceeding $260 million. Because of its focus to tailor its service to customer needs and compete with a large number of small regional carriers, North American proposed the development of a computer scheduling system to manage its large, complex operation efficiently and reap the benefits available through economies of scale. The result was a system called LOADMAP (Load Matching and Pricing) (Powell *et al.*, 1988:24).

Rather than simply minimizing the number of empty miles, LOADMAP considers a myriad of factors to maximize total profits. Some of the data utilized by LOADMAP are the expected number of loads between each pair of geographic regions, the expected direct contribution of each load and its transit time and the expected cost and transit time for moving empty trucks between regions. The real-time inputs to LOADMAP include the location and status of each truck, the number of loads to be moved but not yet assigned to a driver and the direct contribution of each known load as well as its pick-up date and delivery date (Powell *et al.*, 1988:26).

Two approaches were taken to quantify the impact of using LOADMAP for vehicle dispatch. In the first, a comparison was made to three weeks worth of historical dispatches made under the old system. Because the data was historical and trucks were not actually dispatched by LOADMAP, the analysis was limited due to the inability of LOADMAP to better position the fleet of trucks for subsequent runs. Therefore, attention was placed on LOADMAP's ability to minimize total empty miles by optimizing across the fleet. The resulting change in the ratio of loaded to total miles was a 3.8 percent improvement. Next a series of competitions was run between teams of dispatchers and LOADMAP using simulated freight movement requests. The result of all the trials was that LOADMAP consistently provided an 8-10 percent profit increase over the teams, all of which performed similarly (Powell *et al.*, 1988:37-38).

After implementation of the LOADMAP system, North American compiled a list of significant impacts on management philosophy changes as a result of LOADMAP's use. While most of the impacts do not directly relate to military airlift operations, two which have potential for application to Air Mobility Command follow.

> Operating on a national scope: Planners, who each manage a group of regions, used to give priorities to loads in their own regions. With LOADMAP, planners often reposition trucks across regional boundaries since each load and move is evaluated on the basis of its contribution to system-wide profit. (Powell *et al.*, 1988:36)
>
> Real-time load evaluation: Prior to LOADMAP, Operations and Sales would almost always accept loads from customers, then determine how to provide a truck to service the load. Now management believes that through the use of LOADMAP's results, loads can be screened at order entry for impact on the current system. Loads can then be accepted or rejected on the basis of the customer's priority and the load's contribution at the time of order registration. This alleviates the problem of accepting a load and then not being able to perform the service. (Powell *et al.*, 1988:37)

Burlington Motor Carriers.

In 1995, Burlington Motor Carriers, a leading truckload carrier with over 1,200 trucks, contracted with CASTLE Laboratory at Princeton University to develop and implement an optimization model to assist planners in assigning drivers to loads. This model further developed the basic strategies utilized in LOADMAP but added more advanced algorithms and increased the number of input parameters, such as the ability to accommodate driver requests to return home. In addition to developing and installing the model, CASTLE Laboratory used the project to study the implementation process for optimization models in an attempt to learn why dispatchers do not always follow the model recommendations (Powell *et al.*, 2002:571-574).

While the human implementation considerations are beyond the scope of this paper, Powell's study did lead the development team to examine and compare the actual dispatch performance using the system against the probable results if the optimization model recommendations had been followed exactly. The three areas studied were: empty miles driven (for the driver actually assigned versus the driver the model would have assigned), whether or not the load was picked up on time and whether or not the load assigned routed the driver back home. The average performance was measured each day for the three dimensions of the actual dispatches versus the model recommendations for several hundred dispatches per day. In many cases, the actual dispatch performance exceeded the model recommendation in some and even all of the dimensions for a single assignment, but rarely did the actual dispatch performance surpass the model when averaged over all the loads for an entire day. The study found that if the dispatchers had followed the model recommendations, "the empty miles would have been reduced between 5 percent and 10 percent, on-time service would have improved between 1 percent and 3 percent, and routing drivers through home would have improved between 1 percent and 4 percent" (Powell *et al.*, 2002:577).

With this understanding of how Air Mobility Command currently schedules airlift, the tools available to analyze airlift and efforts within the motor carrier industry to improve efficiency, Chapter 3 details the effort to improve airlift scheduling.

Chapter 3 –Methodology

Overview

The methodology employed to explore schedule optimization for Air Mobility Command airlift missions consisted of two processes. To begin, a means of measuring scheduling efficiency is explored to form a basis for comparison. This measure of efficiency is then applied to a historical mission set. Once the scheduling efficiency of the historical mission set was measured, the next step was to attempt improvement of the schedule to determine if any significant increase in efficiency could be achieved. This was accomplished using two methods with an increasing level of sophistication. The first was a simple heuristic approach of examining selected scheduled missions for each of the three aircraft types to find opportunities to combine separate missions into one to eliminate or reduce inactive positioning or depositioning legs. The second method was a refinement of the first through focused selection of certain mission profiles to permit a more thorough improvement process. The final section is a case study analysis involving the use of software developed by the Department of Operations Research and Financial Engineering at Princeton University.

Historical Airlift Mission Scheduling Efficiency

In order to determine if the efficiency of airlift scheduling can be improved, it is first necessary to determine a method for measuring scheduling efficiency. The research began by investigating if the Tanker/Airlift Control Center already tracks this information and found there is no current process for tracking either scheduled or actual efficiency in terms of movement of empty versus loaded aircraft. Since no suitable measure existed, a measure was developed through analysis of Air Mobility Command assigned mission numbers.

Each Air Mobility Command airlift mission is scheduled and tracked using a discreet twelve character alpha-numeric mission number. The mission numbers are composed of groups of digits which convey information about the mission, usually composed of four groups of characters. The first three characters are the prefix, the fourth through the seventh characters are the basic mission number, the eighth and ninth characters are the suffix and the tenth through twelfth characters are digits representing the Julian date of the scheduled origination of the mission segment. An entire mission is composed of one or more legs from originating station to onload location, onload to offload location and return to originating location. While the basic mission number remains constant, the prefix and date portions of the mission number may change on each leg. The second character of the mission number for Contingency, Exercise, Channel and Special Assignment Airlift Missions indicates the purpose of that leg as shown in Table 2.

Table 2. Mission Number Second Character Encode/Decode (Air Mobility Command Mission ID, 2003)

Channel		Special Assignment Airlift Mission		Contingency/Exercise	
B	Channel Cargo	W	TALCE/Equipment Support	M	Onload to Offload
K	Channel PAX	A	Onload to Offload	P	Aerial Refueling
Q	Channel Mixed	L	Air Evac	J	Positioning to onload
L	Air Evac	J	Positioning to onload	V	Depositioning from offload
J	Positioning to first onload	V	Depositioning from offload		
V	Depositioning from offload to new mission or home station				

Utilizing this information, it is a straightforward process to determine the planned active and inactive legs of each mission.

Armed with this information, a set of historical missions was obtained and analyzed. As detailed in the assumptions, the desire was to capture a set of missions which represented, as much as possible, the "normal" activity of Air Mobility Command. Since there has been a concentration of activity in Southwest Asia in the aftermath of the terrorist attacks on 11 September 2001, the period from 1 to 31 August 2001 was chosen for the analysis. Using the Air Mobility Command History System within the Global Decision Support System, Air Mobility Command's primary command and control tracking system, all airlift missions which operated during this period were extracted and imported into Microsoft Excel. An example of the result is shown in Figure 1.

MDS	TAIL NO	MISSION ID	LEG	MISSION TYPE	DEPART ICAO	DEPART SCHED TIME	ARRIVE ICAO	ARRIVE SCHED TIME	FLYING TIME	WEIGHT	PAX
C017A	70048A	XJB08010A213	100	CHANNEL	KCHS	1213/01:30	KDOV	1213/02:45	1.4		6
C017A	90058A	PBC05E100208	400	CHANNEL	YSRI	1211/23:00	YBAS	1212/02:10	3.3	6340	2
C017A	90170A	PBC05030B213	400	CHANNEL	RJTY	1213/01:15	RKSO	1213/03:35	1.8	38480	3
C017A	60007A	ABC08830B212	300	CHANNEL	PHIK	1213/02:10	RJTY	1213/10:55	7.9	5919	
C017A	23292A	ABC08340A212	400	CHANNEL	RKSO	1212/04:10	PAED	1212/12:50	9.1	43280	
C017A	60005A	AQB20T10A213	1000	CHANNEL	EDDF	1213/04:30	LTAG	1213/09:45	4.7	17765	

Figure 1. Air Mobility Command History System Report Sample

Each line within Figure 1 details one leg of a given airlift mission and the data elements are described in Table 3.

Table 3. Air Mobility Command History System Report Data Elements

Data Element	Description
MDS	Mission Design Series (Aircraft Type)
TAIL NO	Tail number of the specific aircraft flying the leg
MISSION ID	Twelve character alpha-numeric mission number
LEG	Leg number identification within the mission (100 denotes the first leg, 200 the second leg, etc.)
MISSION TYPE	Type of mission such as Contingency, Channel or Special Assignment Airlift Mission
DEPART ICAO	Identification of the departure airfield according to the International Civil Aviation Organization (ICAO)
DEPART SCHED TIME	The scheduled departure date and time where the first character is the last digit of the year, the next three digits are the Julian day and the last four digits are the time of day in Greenwich Mean Time
ARRIVE ICAO	Identification of the destination airfield according to the International Civil Aviation Organization (ICAO)
ARRIVE SCHED TIME	The scheduled arrival date and time where the first character is the last digit of the year, the next three digits are the Julian day and the last four digits are the time of day in Greenwich Mean Time
FLYING TIME	The flight time calculated from actual departure time to actual arrival time
WEIGHT	Total weight of passengers and cargo manifested
PAX	Total number of passengers manifested

Since the research is on inter-theater airlift missions scheduled by the Tanker/Airlift Control Center, the analysis is limited to the three aircraft types which perform most of these missions in this role: the C-141, the C-17 and the C-5. The total missions and sorties (legs) for each aircraft type and mission type are shown in Table 4.

Table 4. Historical Mission Totals

	C-141		C-17		C-5	
MISSION TYPE	MISSIONS	SORTIES	MISSIONS	SORTIES	MISSIONS	SORTIES
AIREVAC			4	13		
AIRSHOW	1	2	6	11		
CHANNEL	75	340	187	728	87	336
CONTING	14	49	29	115	36	149
EXERCISE	2	9	4	25	15	64
GUARDLFT	4	18			5	17
JAATT	3	15	45	151	1	2
ORI	1	3			5	13
REDEP	1	2				
REFUEL	27	30	37	37		
SAAM	37	148	43	221	26	73
SUPPORT	23	37	3	7	20	44
TRAINING	122	284	197	348	144	310
TRANSFER	2	2	1	1	1	1
Total	312	939	556	1657	340	1009

Many of these mission types, especially Training and Joint Airborne/Air Transportability (JAATT), are not planned by the Tanker/Airlift Control Center and are instead controlled by the individual Airlift Wings. Furthermore, certain mission types are primarily intended to support aircrew and user training and are intentionally planned to maximize objectives other than efficient movement of cargo. In order to focus on missions within the control of the Tanker/Airlift Control Center which could benefit most from an increase in scheduling efficiency, the analysis is limited to Channel, Contingency, Exercise and Special Assignment Airlift Missions. These four mission types constituted 64.3% of the total hours flown by these aircraft types during this time period.

Within the Excel spreadsheet, all mission legs except for the three aircraft types and four mission types were eliminated. Then functions were designed to determine the status for each leg as active or not based on the second character of the mission number. For analysis purposes, an active leg is one which is scheduled to fly from the onload location to the offload location or any leg in between. A function was also designed to derive the scheduled flight time between the scheduled departure time and the scheduled arrival time, rather than using the actual flight time because the emphasis is on the planning function rather than the execution function. For each aircraft type and the entire fleet, the active hours and total hours were summed by mission type. Because Contingency and Exercise missions are planned by the same directorate within the Tanker/Airlift Control Center, those missions were combined. The measure of scheduling efficiency, the Operating Ratio, is the ratio of active hours scheduled to total hours scheduled expressed as a percentage. An Operating Ratio of 100% would represent perfect efficiency where no aircraft were scheduled to fly empty. In order to measure a change in scheduling efficiency due to changes in scheduling methodology, it is assumed the total active hours will remain constant since the same amount of cargo requires transport between the same locations, but the total hours are reduced due to a reduction in inactive (or empty) hours. An increase in overall efficiency would be indicated by an increase in Operating Ratio. In addition, the percentage each mission type contributes to the total hours flown for the four mission types analyzed was computed. This information is summarized in Table 5.

Table 5. Historical Airlift Mission Analysis

C-141	Combined	Channel	Cont/Exer	SAAM
Active Hours (hh:mm)	1517:10	1101:55	154:00	261:15
Total Hours (hh:mm)	2142:15	1356:07	279:40	506:28
Operating Ratio	70.82%	81.26%	55.07%	51.58%
% Total C-141 Hours	100.00%	63.30%	13.05%	23.64%
C-17	Combined	Channel	Cont/Exer	SAAM
Active Hours (hh:mm)	4576:45	3609:14	464:01	503:30
Total Hours (hh:mm)	5392:16	3894:13	741:41	756:22
Operating Ratio	84.88%	92.68%	62.56%	66.57%
% Total C-17 Hours	100.00%	72.22%	13.75%	14.03%
C-5	Combined	Channel	Cont/Exer	SAAM
Active Hours (hh:mm)	2861:52	2100:35	608:43	152:34
Total Hours (hh:mm)	3691:39	2300:14	1127:31	263:54
Operating Ratio	77.52%	91.32%	53.99%	57.81%
% Total C-5 Hours	100.00%	62.31%	30.54%	7.15%
Total Fleet	Combined	Channel	Cont/Exer	SAAM
Active Hours (hh:mm)	8955:47	6811:44	1226:44	917:19
Total Hours (hh:mm)	11226:10	7550:34	2148:52	1526:44
Operating Ratio	79.78%	90.21%	57.09%	60.08%
% Total Hours	100.00%	67.26%	19.14%	13.60%

Schedule Improvement

Simple Heuristic

The simple heuristic process was nothing more than a “common sense” review of the monthly schedule to increase efficiency by flowing missions together where it reduced inactive legs. As indicated in Table 4, there were 556 missions flown during the month for all aircraft and mission types under review. However, the overall operating ratio for Channel missions for the three aircraft types was already extremely high at 90%. To reduce the number of missions to be reviewed and with the assumption there is little opportunity to increase the operating efficiency for Channel missions, only Contingency, Exercise and Special Assignment Airlift Missions were examined. This reduced the number of missions to 207. Furthermore, each aircraft type was considered separately because of the different capabilities of each.

The reduced mission set was sorted chronologically by aircraft type. The primary examination was of missions positioning and depositioning empty to and from the Continental US to Europe, the Middle East and the Pacific regions. The missions were matched to complimentary movement requirements where inactive legs could be eliminated by combining two separate missions into one. While doing this, the movement dates for the linked missions were adjusted by no more than plus or minus one day. Since linking missions together extends the time away from home station for the aircraft and crew, impacting maintenance and personnel, linked missions longer than twelve days were avoided.

Focused Heuristic

The focused heuristic method was simply a more thorough and refined application of the same process as the simple heuristic method. First, the pool of missions under consideration was reduced to a single aircraft type, the C-141, and the two main operating bases for that type at the time, McGuire AFB, NJ and McChord AFB, WA. However, unlike the previous method, Channel missions were included. The schedule was then edited to eliminate mission fragments. Mission fragments were those entries where the data did not indicate the full mission profile from departure at home station to return to home station. These fragments occurred for several reasons. Since the data encompassed only one month, missions which originated in the previous month or concluded in the subsequent month were truncated in the original data set. Other missions were incomplete because they flowed to or from an excluded mission type, such as Training or

Support, away from home station. The end result was a set of complete missions originating and terminating at their home stations.

As in the previous method, the missions were then sorted chronologically and examined for opportunities to reduce inactive legs by linking missions together. Unlike the previous method, the cargo movement dates for the linked missions were not adjusted, but the twelve day maximum mission duration was maintained. The reduced mission set allowed for a more thorough review and optimization and included not only overseas missions but Continental US missions as well.

The Optimizing Simulator

Case study analysis of experiments conducted using the Optimizing Simulator software provide an opportunity to compare the results of various scheduling policies. For the experiments, a simulated TPFDD was used which detailed a set of cargo and passengers to be moved from the Continental US to bases in the Middle East. Five aircraft types were utilized (C-141, C-17, C-5, KC-10 and Commercial Narrow Body Cargo) with total movement requirements of approximately four times the capacity of all the aircraft combined. The round trip duration for an aircraft was about four days, so closure would require a minimum of sixteen days if all the capacity of all the aircraft could be utilized. The simulation was run over a 40 day time interval, divided into four hour time periods. The simulator was configured to minimize the total cost of delivery where transportation cost was $0.01 per mile per pound of the capacity of the aircraft, and the penalty for late delivery was $0.04 per pound per period. The simulator also included a cost of $0.12 per hour per pound of capacity for broken aircraft, but these costs are not relevant to this research (Wu *et al.*, 2003:33).

The simulation was run using the same input data five times utilizing five different scheduling policies. The first policy is referred to as rule based, one requirement and one aircraft (RB:R-A). Under this policy, the first available requirement in the TPFDD is selected and matched to the first available aircraft. The combination is then checked for feasibility to determine if the aircraft is compatible with the load, the enroute airfields and the destination airfield. If the combination is not feasible, the next available aircraft is selected and checked. Once a feasible combination is found, the requirement is scheduled against the aircraft and the remaining cargo and passengers for that requirement are updated. The process is repeated until the requirement is fully scheduled and then begins anew with the next requirement. This policy is unique because it is explicitly rule based and does not consider any costs (Wu *et al.*, 2003:24). This process is highly analogous to the scheduling system currently used at the Tanker/Airlift Control Center in the macro sense since there is no system to analyze the complete set of movement requirements and match them to the most cost effective combination of aircraft.

The next two scheduling policies include cost consideration with increasing degrees of complexity. The first of these is myopic policy--one requirement and a list of aircraft (MP:R-AL). With this policy, the first requirement is compared to a list of available aircraft. After performing the same feasibility check, a cost function is introduced to select the aircraft which offers the highest contribution to fulfilling the requirement. Following that is myopic policy with a list of requirements and a list of aircraft (MP:RL-AL) where the entire TPFDD is compared to the available aircraft to form a feasible combination which minimizes the total cost (Wu *et al*., 2003:25). A graphical depiction of these policies is presented in Figure 2.

Rule Based, One Requirement and One Aircraft (RB:R-A) | Myopic Policy, One Requirement and a List of Aircraft (MP:R-AL) | Myopic Policy, a List of Requirements and a List of Aircraft (MP:RL-AL)

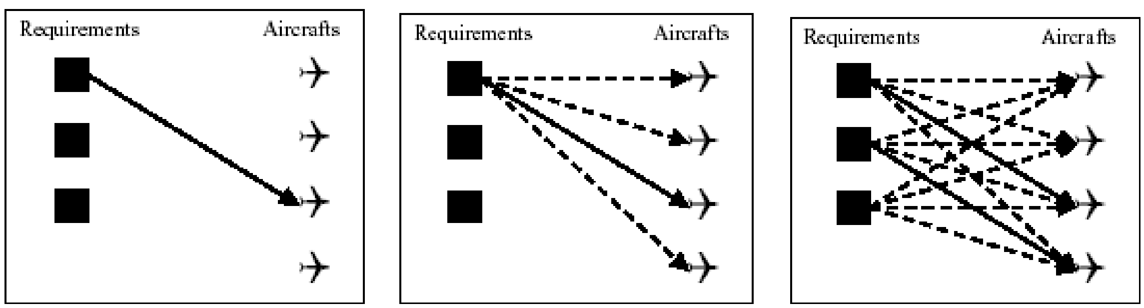

Figure 2. Scheduling Policies (Wu *et al.*, 2003:26)

The last policy is presented in two forms with respect to when information is known and when it can be acted upon. The first form is known now actionable now (KNAN) where current information on remaining requirements and aircraft is used to schedule movement of aircraft currently available. The other form, known now actionable future (KNAF), can achieve tradeoffs between transportation costs and late costs by deferring movement to an aircraft becoming available in the future if the capabilities of the aircraft offset the delay. This also introduces the possibility that decisions made now for future execution may be changed if circumstances change such as loss of the aircraft due to maintenance (Wu *et al.*, 2003:25).

After exploration of a means to measure scheduling efficiency and its application to a historical mission set, the scheduling efficiency of a historical mission set was analyzed to determine if improvements could be made. Chapter 4 details the results of this analysis and compares them to the output from the Optimizing Simulator.

Chapter 4 – Data Analysis

Airlift Mission Scheduling Efficiency

In order to establish a baseline for comparison to determine if worthwhile improvements can be made to improve airlift scheduling efficiency, the following data, shown in Table 6, was generated as outlined in Chapter 3. For the three aircraft types and four mission types reflected, the total hours flown and active hours flown were captured for the period from 1 August 2001 through 31 August 2001. The operating ratio is the active hours divided by the total hours, which reflects the percentage of the total hours flown the mission was scheduled to move cargo and passengers in support of user requirements. This data reflects scheduled usage only and does not indicate whether or not the aircraft actually carried anything. For comparison purposes, any increase in the operating ratio to move the same requirements on the same aircraft would represent a more efficient use of resources. An operating ratio of 100% would represent perfect efficiency, but is considered to be unachievable due to the disparate basing locations of airlift providers and airlift users.

Table 6. Historical Airlift Mission Analysis

C-141	Combined	Channel	Cont/Exer	SAAM
Active Hours (hh:mm)	1517:10	1101:55	154:00	261:15
Total Hours (hh:mm)	2142:15	1356:07	279:40	506:28
Operating Ratio	70.82%	81.26%	55.07%	51.58%
% Total C-141 Hours	100.00%	63.30%	13.05%	23.64%
C-17	Combined	Channel	Cont/Exer	SAAM
Active Hours (hh:mm)	4576:45	3609:14	464:01	503:30
Total Hours (hh:mm)	5392:16	3894:13	741:41	756:22
Operating Ratio	84.88%	92.68%	62.56%	66.57%
% Total C-17 Hours	100.00%	72.22%	13.75%	14.03%
C-5	Combined	Channel	Cont/Exer	SAAM
Active Hours (hh:mm)	2861:52	2100:35	608:43	152:34
Total Hours (hh:mm)	3691:39	2300:14	1127:31	263:54
Operating Ratio	77.52%	91.32%	53.99%	57.81%
% Total C-5 Hours	100.00%	62.31%	30.54%	7.15%
Total Fleet	Combined	Channel	Cont/Exer	SAAM
Active Hours (hh:mm)	8955:47	6811:44	1226:44	917:19
Total Hours (hh:mm)	11226:10	7550:34	2148:52	1526:44
Operating Ratio	79.78%	90.21%	57.09%	60.08%
% Total Hours	100.00%	67.26%	19.14%	13.60%

One trend is immediately obvious across all three aircraft types; channel missions consistently achieve significantly higher operating ratios. This is attributed to the cyclical nature of these missions and the customers they support. Since these missions are primarily for the sustainment of permanent forward bases or forces deployed for long-term contingency operations, they are routinely planned to provide movement of cargo and personnel going to and returning from the supported destination. In contrast, Contingency, Exercise and Special Assignment Airlift Missions usually require one way movement between locations, at least in the short term.

The remaining mission types constitute 32.7% or 3,676 of the total hours considered for this time period. The consolidated fleet operating ratio for these missions varied from 57.09% to 60.08% indicating these missions were scheduled to fly empty over one third of the time. The question is whether changes to the scheduling system can improve these measures. In the following section, three methods are explored to address this question.

Schedule Improvement

Simple Heuristic

Using the methods described in Chapter 3, a subset of the historical missions was subjected to a simple heuristic procedure across all three aircraft types to determine if an improvement in the operating ratio could be achieved. Because Channel missions already achieved a fleet wide 90% score, they were excluded from this method. By simply examining the schedule for opportunities to tie missions together where there were complimentary requirements going in opposite directions, the results shown in Table 7 were achieved.

Table 7. Simple Heuristic Results

Original Schedule					Improved Schedule		
C-141	Combined	Channel	Cont/Exer	SAAM	Cont/Exer	SAAM	Hrs Saved
Active Hours (hh:mm)	1517:10	1101:55	154:00	261:15	154:00	261:15	
Total Hours (hh:mm)	2142:15	1356:07	279:40	506:28	228:45	492:53	64:30
Operating Ratio	70.82%	81.26%	55.07%	51.58%	67.32%	53.00%	
% Total C-141 Hours	100.00%	63.30%	13.05%	23.64%			3.01%
C-17	Combined	Channel	Cont/Exer	SAAM	Cont/Exer	SAAM	Hrs Saved
Active Hours (hh:mm)	4576:45	3609:14	464:01	503:30	464:01	503:30	
Total Hours (hh:mm)	5392:16	3894:13	741:41	756:22	741:41	756:22	0:00
Operating Ratio	84.88%	92.68%	62.56%	66.57%	0.00%	0.00%	
% Total C-17 Hours	100.00%	72.22%	13.75%	14.03%			0.00%
C-5	Combined	Channel	Cont/Exer	SAAM	Cont/Exer	SAAM	Hrs Saved
Active Hours (hh:mm)	2861:52	2100:35	608:43	152:34	608:43	152:34	
Total Hours (hh:mm)	3691:39	2300:14	1127:31	263:54	1081:41	263:54	45:50
Operating Ratio	77.52%	91.32%	53.99%	57.81%	56.27%	57.81%	
% Total C-5 Hours	100.00%	62.31%	30.54%	7.15%			1.24%
Total Fleet	Combined	Channel	Cont/Exer	SAAM	Cont/Exer	SAAM	Hrs Saved
Active Hours (hh:mm)	8955:47	6811:44	1226:44	917:19	1226:44	917:19	
Total Hours (hh:mm)	11226:10	7550:34	2148:52	1526:44	2052:07	1513:09	110:20
Operating Ratio	79.78%	90.21%	57.09%	60.08%	59.78%	60.62%	
% Total Hours	100.00%	67.26%	19.14%	13.60%			0.98%

The simple heuristic method provided positive, but limited improvements. The fleet operating ratio improvement was 2.69% for Contingency/Exercise missions while Special Assignment Airlift Missions were improved by just 0.54%. As shown in the table, the active hours for these mission types remained constant before and after improvement, but the total hours were reduced by elimination of overlapping positioning and depositioning legs. Overall, schedule improvement resulted in a savings of 110 flight hours, or 0.98% of the total hours flown for the month (including Channel missions). Interestingly, no opportunity for schedule improvement was found for C-17 missions. This is attributed to the recent introduction of the C-17 into the fleet during the data collection period when special emphasis was placed by Air Mobility Command leadership and planners on high utilization of the aircraft. The operating ratios for C-17 Contingency, Exercise and Special Assignment Airlift missions was already 7%-9% higher than the other aircraft types before application of the simple heuristic, lending support to the view that any level of focus on improving scheduling efficiency will have positive results.

Focused Heuristic

In a second attempt to improve the historical mission set, a more thorough procedure was employed using the focused heuristic method detailed in Chapter 3. For this approach, the subset under consideration consisted of all C-141 missions from two main operating bases, one on the east coast and one on the west coast. The mission set was reduced to exclude any fragments of missions occurring due to overlap from the previous or subsequent months. Again through manual analysis, opportunities to reduce inactive positioning and depositioning legs were explored utilizing simple business rules. The results are shown in Table 8.

Table 8. Focused Heuristic Results

Original Schedule					
C-141	Combined	Channel	Cont/Exer	SAAM	
Active Hours (hh:mm)	608:50	341:50	82:35	184:25	
Total Hours (hh:mm)	946:42	418:49	167:05	360:48	
Operating Ratio	64.31%	81.62%	49.43%	51.11%	
% Total C-141 Hours	100.00%	44.24%	17.65%	38.11%	
Improved Schedule					
C-141	Combined	Channel	Cont/Exer	SAAM	Hrs Saved
Active Hours (hh:mm)	608:50	341:50	82:35	184:25	
Total Hours (hh:mm)	897:27	398:04	133:05	366:18	49:15
Operating Ratio	67.84%	85.87%	62.05%	50.35%	
% Total C-141 Hours	100.00%	44.36%	14.83%	40.82%	5.20%

The results of the focused heuristic method were much improved over the simple heuristic with a 5.20% reduction in overall hours required to move the same requirements. The Channel Mission operating ratio was only slightly increased from 81.62% to 85.87%, but Contingency and Exercise missions achieved a significant increase from 49.43% to 62.05%. As in the simple heuristic method, the active hours remained constant with gains occurring from reduction in total hours. The Special Assignment Airlift Mission operating ratio actually decreased slightly from 51.11% to 50.35%. This was due to a slight increase in total hours caused by movement of aircraft to position them from one type of mission to another. In this case, the decrease is irrelevant when compared to the overall improvement in the operating ratio, since the same positioning legs could be attached to the other mission types where necessary to achieve increases in all mission types without changing the overall results. For example, if a mission transitions from a Contingency to a Special Assignment Airlift Mission, the leg between the two mission segments to move the aircraft from where the previous mission ends to where the next begins can be attached to either mission without changing the overall total number of hours flown for the combined missions.

Based on the results from the simple heuristic method, the results achieved for the C-141 fleet may be more optimistic than for the combined fleet of aircraft. Under the simple heuristic method, the percentage of hours saved was 3.01% of the total original hours flown for the C-141, but 0.0% for the C-17 and 1.24% for the C-5. One could speculate that by applying the same relative improvement of 2.19% (5.20%-3.01%) to the other aircraft types, they would achieve a savings of 2.19% and 3.43% respectively.

Applying a weighted average based on the total hours flown, the overall savings of total hours flown would be 3.17% or approximately 356 hours.

Optimizing Simulator

Analysis of experiments conducted using the Optimizing Simulator developed by the Department of Operations Research and Financial Engineering at Princeton University yield the results for various scheduling policies shown in Figure 3.

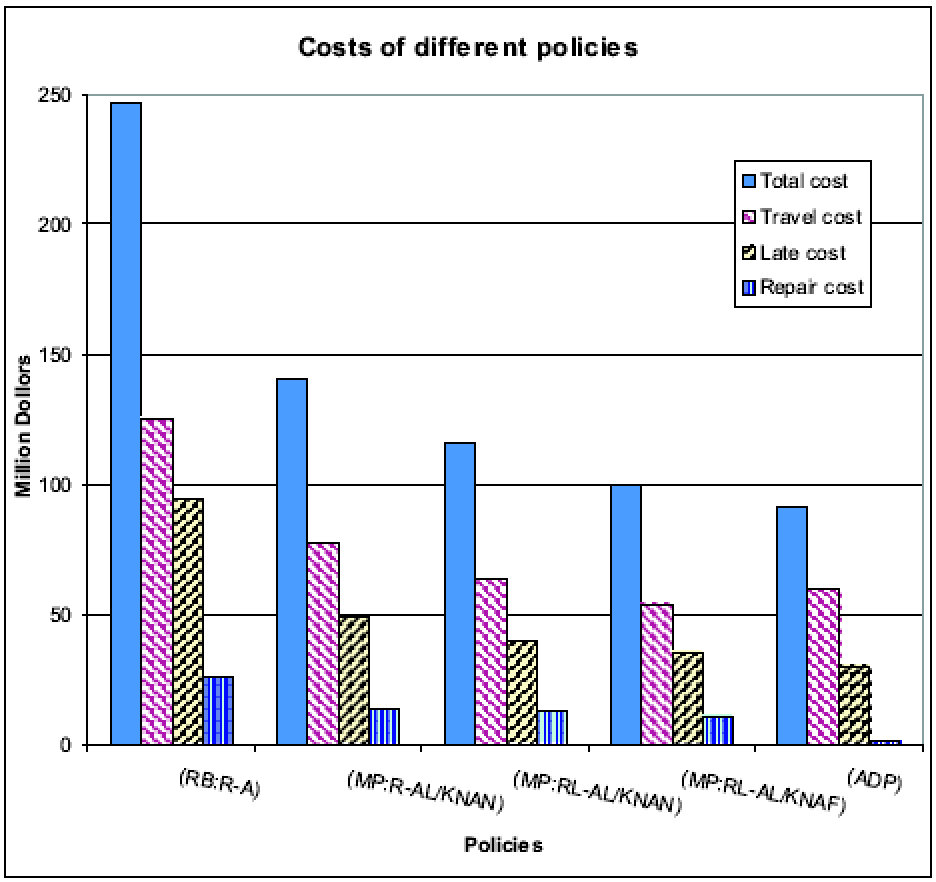

Figure 3. Scheduling Policy Cost (Wu *et al.*, 2003:35)

Each set of bars in Figure 3 represent various costs associated with movement of a set of TPFDD requirements from the Continental US to the Middle East. For purposes of this research, repair cost for aircraft is not relevant; therefore, the total costs are not considered. The first set of bars is rule based, one requirement and one aircraft (RB:R-A) and serves as the baseline for the subsequent policies. The second set of bars is myopic policy, one requirement and a list of aircraft, known now actionable now (MP:R-AL/KNAN). The third is myopic policy, a list of requirements and a list of aircraft, known now actionable now (MP:RL-AL/KNAN) and the fourth is myopic policy, a list of requirements and a list of aircraft, known now actionable future (MP:RL-AL/KNAF). The last set of bars (ADP) is a scheduling policy based on Approximate Dynamic Programming which is beyond the scope of this research. The cost shown along the vertical axis represents the total cost to transport the entire TPFDD based on transportation costs of $0.01 per mile per pound of the capacity of the aircraft, and a penalty for late delivery of $0.04 per pound per time period. The actual costs are not necessarily considered accurate or relevant, but the cost relationship between policies is of interest. The first policy is strictly rule based and matches the first available requirement to the first available aircraft. The remaining policies seek to minimize costs with increasing levels of complexity. As indicated in Figure 3, as the simulation introduces cost improvement into the scheduling policy, transportation costs from the first policy to the fourth are reduced by approximately 65% and late costs are reduced approximately 60%. These dramatic cost savings are achieved through a much more complex process than a simple improvement in operating ratio, but represent the realm of possibility derived from use of information technology combined with analytic modeling.

While cost is an important measure of airlift efficiency, another critical dimension of airlift is effectiveness. One measure of airlift effectiveness is throughput; the amount of cargo and passengers capable of being delivered by the airlift system over a given unit of time. Figure 4 is a plot of the throughput curves for each of the scheduling policies applied to the scenario discussed earlier. The vertical axis indicates total cumulative pounds of cargo delivered per time period across the horizontal axis in four hour increments. Similar to the cost comparison in Figure 3, as the scheduling policy is changed from a simple rule based strategy to ones which consider costs of transportation and late delivery, the throughput is improved.

Through analysis of the historical mission set, it has been shown schedule efficiency improvements are possible through a relatively simple process to increase the operating ratio. These results are supported by experiments run using the Optimizing Simulator to compare various scheduling policies. Chapter 5 uses these results to address the original problem statement and related research questions.

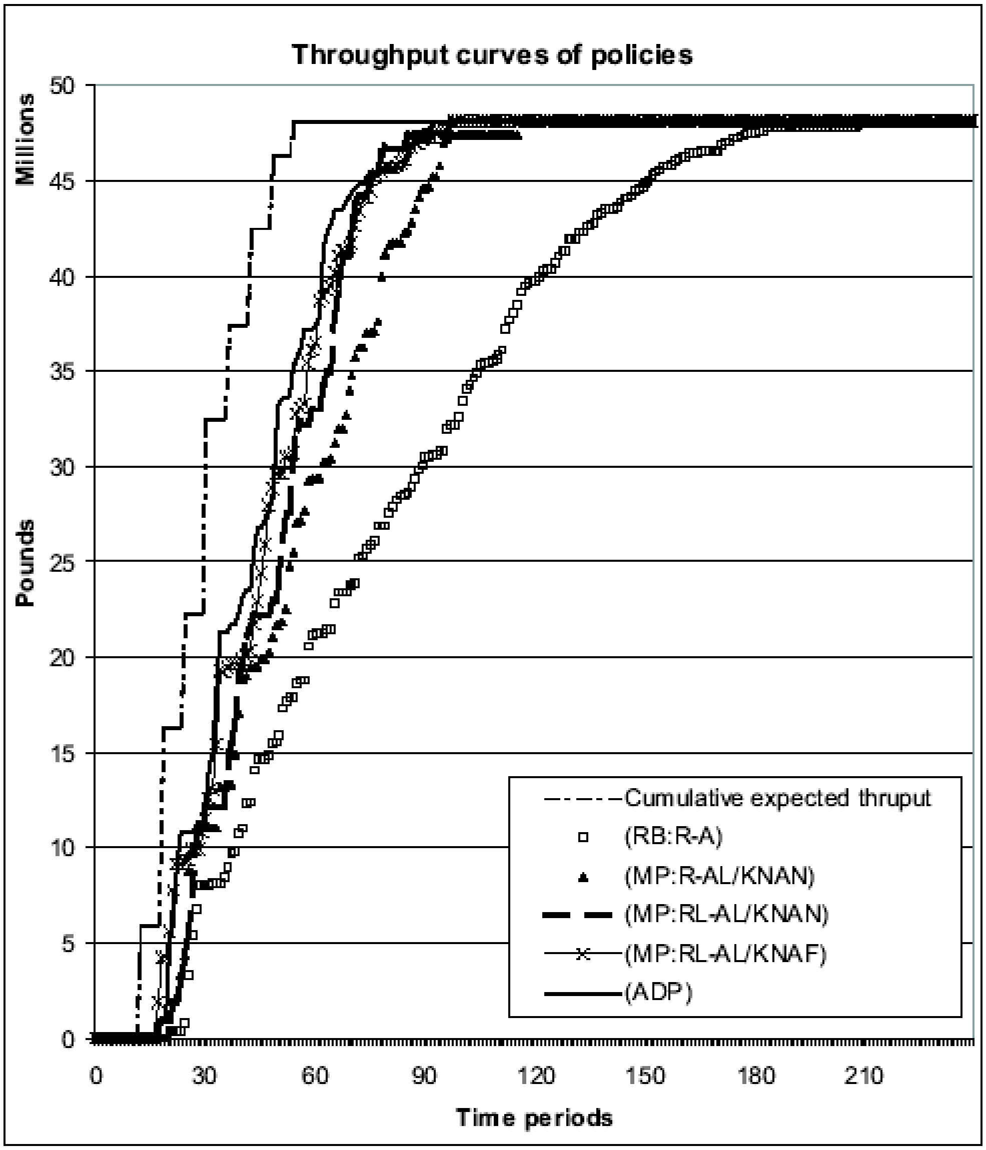

Figure 4. Scheduling Policy Throughput Curves (Wu *et al.*, 2003:36)

Chapter 5 – Conclusions and Recommendations

Research Results

The question which formed the basis for this research effort was, "Can the scheduling effectiveness of airlift resources be improved by study and adoption of scheduling practices employed by the motor carrier industry?" In order to answer the research question, the following investigative questions were employed with the corresponding results.

1. How does the Tanker/Airlift Control Center currently schedule airlift movements?

Through review of Air Force and Air Mobility Command publications and the author's experience working at the Tanker/Airlift Control Center, it was shown there are three directorates which separately plan airlift missions to support various customers. Mission planners typically schedule each mission to originate from home station, proceed to an onload location to receive cargo and passengers, proceed to an offload location to discharge cargo and passengers and return to home station. When cargo and passengers require one-way transportation to or from overseas location, aircraft are often flown empty for a significant number of hours on positioning or depositioning legs. Although opportunities exist to utilize the same aircraft to move complimentary requirements going in opposite directions, there is no formal process within the Tanker/Airlift Control Center for the various directorates to share resources.

2. How efficiently are airlift assets scheduled?

Because there appeared to be an opportunity to improve the efficiency of airlift missions, a method for measuring scheduling efficiency was explored. Since no existing measurement system could be found, one was developed through analysis of Air Mobility Command mission numbers. Within the unique twelve character mission identifier assigned to each mission flown by Air Mobility Command, it was found the second character indicates the purpose of each leg as active or inactive for certain types of missions. By combining this information with the scheduled flight time for each leg, it was possible to determine the active scheduled hours and total scheduled hours for each mission. By applying this analysis to a set of historical missions captured from the Global Decision Support System, it was possible to determine an operating ratio of active hours flown to total hours flown by aircraft and mission type. The operating ratio is expressed as a percentage of the total flight hours the aircraft is scheduled to transport cargo and passengers in support of customer requirements. An increase in the operating ratio would represent a more efficient use of airlift resources.

For Contingency, Exercise, Channel and Special Assignment Airlift Missions flown during the period from 1 August 2001 to 31 August 2001 by C-141, C-17 and C-5 aircraft, the fleet combined operating ratio was 79.78%. While the overall Channel mission operating ratio was especially high at 90.21%, Contingency/Exercise and Special Assignment Airlift Mission operating ratios were only 57.09% and 60.08%, respectively. As suspected, Air Mobility Command airlift aircraft are scheduled to fly empty a significant amount of the time.

3. How does the motor carrier industry schedule cargo movements?

Until the mid-1990s, the motor carrier industry was highly regulated by the Federal Government which set rates and controlled routes over which trucks could operate. In many cases, companies were only allowed to haul freight in one direction on a particular route and empty backhauls were common. However, since rates were controlled by the Interstate Commerce Commission and were based on actual costs plus a "fair" profit, there was little incentive to improve efficiency. After the industry was deregulated in the 1990s, almost all controls were removed and companies were free to negotiate rates with customers. This led to the desired result of deregulation of reduced rates through competition. In this new operating environment, motor carriers were forced to find ways to improve efficiency to remain competitive. In the period since deregulation of the motor carrier industry in 1995, private industry motor carriers have developed optimization and scheduling systems and software to strengthen their advantage in an increasingly competitive marketplace. These systems have been successfully employed to reduce the number of empty miles driven, improve routing of drivers back to their area of residence and increase overall revenues.

4. Can practices employed by the motor carrier industry be adopted to improve airlift scheduling?

Central to this research effort is the issue of whether the practices used by motor carriers to improve efficiency and profitability are applicable to Air Mobility Command. It is the author's opinion the challenges faced by truckload motor carriers are very analogous to airlift. Consider the following quote from an article which discusses application of optimization models to motor carriers.

> The most obvious objective is to minimize the total number of miles a driver has to move empty to cover the load (carriers typically pay by the mile). But there are a number of other goals the carrier must juggle. Loads have time windows in which they need to be picked up and delivered. Loads may require special driver skills (such as experience crossing a border, or the training to handle hazardous materials) or equipment (longer trailers, refrigerated trailers, or air-ride shock absorbers). Perhaps the most difficult challenge is the problem of getting drivers home. A long-haul truckload driver may be away from home for two weeks or more. After a period of time on the road, a driver will request to be put on a load that gets him close to his home (although drivers vary in their willingness to be away from home). (Powell *et al.*, 2002:571-572).

One could replace the word "driver" in the preceding quote with the word "aircrew" and have a near perfect description of many of the challenges faced by the Tanker/Airlift Control Center mission planners including minimizing movement of empty aircraft, TPFDD pickup and delivery dates, selection of appropriate aircraft type, special aircrew qualifications and scheduled return times to home station.

5. What gain in efficiency could be expected by adoption of these practices?

In order to determine if lessons learned from the motor carrier industry can help improve the airlift scheduling efficiency of Air Mobility Command, the same data set of missions used for measuring current efficiency in Question 2 was analyzed using two methods. First, the entire set was reviewed for opportunities to combine separate missions into one where complimentary payload movements existed to eliminate redundant positioning and depositioning legs. Since this most always results in a longer single mission to replace multiple missions flown by different aircraft, the new missions were limited to twelve days. Also, the aircraft type supporting the mission was not changed. Since Channel missions already enjoyed a high operating ratio of 90.21%, only Contingency/Exercise and Special Assignment Airlift Missions were considered. Using this method, the operating ratio was improved by 2.69% for Contingency/Exercise missions and 0.54% for Special Assignment Airlift Missions. The total hours flown was reduced by 110 hours, or 0.98% of the total hours flown for the month (including Channel missions).

The second optimization method was a more thorough application of the same basic method used in the first. The data set was reduced to a single aircraft type operated from two main bases, but included all mission types. The data set was further reduced to eliminate any fragments of missions caused by run over from the previous or subsequent months or change of mission type away from home station. This method yielded improved results with an increase in the overall operating ration of 3.53%. Channel missions were little improved due to an already high score, but Contingency/Exercise missions achieved an impressive 12.62% improvement. The total number of hours required to deliver the same requirements was reduced by 49 hours or 5.2%.

A final examination of possible scheduling efficiency improvement was accomplished through a case study of experiments conducted using software developed at Princeton University. In these experiments, a set of TPFDD requirements was subjected to simulated scheduling and movement runs using various scheduling policies. The scheduling policies progressed from one which simply matched the first available load to the first available aircraft to more complex models that sought to minimize total transportation and late delivery costs. It was shown the results of automated scheduling reduced transportation costs approximately 65%, reduced late costs by approximately 60% and increased overall throughput of the airlift system.

So, the answer to the question "Can the scheduling effectiveness of airlift resources be improved by study and adoption of scheduling practices employed by the motor carrier industry," is a resounding yes in the author's opinion.

Areas for Further Study

Given the author's conclusion that the utilization of Air Mobility Command airlift resources can be made more efficient through scheduling optimization, the next logical step is to investigate implementation of a new scheduling system. Some areas which will require exploration are the organizational structure of the Tanker/Airlift Control Center and information technology support.

As previously discussed, the existence of three distinct planning branches within the Tanker/Airlift Control Center contributes to the reduced efficiency currently achieved because there is no formal system for the branches to share airlift resources. The three branches are organized in this manner to serve the unique needs of the customers they support. The first issue is whether the separate branches are really necessary, or if they could be combined into one planning operation with sufficient flexibility to serve all customers. If it is determined the current structure should be preserved, then formal procedures to promote sharing of resources should be explored. One solution is to alter the current process of airlift planners scheduling the entire mission from home station back to home station. Instead, a system could be developed where the planners only input the required active legs of their missions. Then, at a set time prior to mission execution, Mobility Management would analyze all the movement requirements and combine complimentary active legs into complete missions serving multiple customers.

This process could be further enhanced through the use of information technology support.

In order to achieve the greatest improvement in efficiency, it will be necessary for Air Mobility Command to employ enhanced technology support to analyze and optimize the scheduling of airlift resources. Although this research has shown some improvement can be achieved using manual methods, the process is time consuming and labor intensive. Examples from the motor carrier industry indicate information technology for application to this class of problem already exists.

Summary

This research explores the similarity between Air Mobility Command airlift scheduling and US motor carrier industry scheduling with respect to improving efficiency. It begins with an overview of Air Mobility Command's organization and functional relationships with regard to scheduling of airlift assets and a review of currently fielded airlift modeling and simulation systems. This is followed by a review of the US motor carrier industry with an emphasis on scheduling and efforts to improve efficiency in that industry as well as the results.

After reviewing practices employed by the motor carrier industry to improve efficiency, similar methodology is applied to a set of historical airlift missions to measure and attempt to improve the scheduled efficiency of these missions. A measure of efficiency, the operating ratio, is developed through analysis of Air Mobility Command mission numbers. The operating ratio represents the percentage of flight hours a mission or group of missions is scheduled to transport cargo and passengers. A higher operating ratio represents greater efficiency through a reduction in hours an aircraft is operated empty. It was found Channel missions achieved a fleet wide operating ratio of over 90% while Contingency, Exercise and Special Assignment Airlift Missions range from 57% to 60%.

After determining the efficiency of the historical mission set, two basic methods of optimization were applied to determine if the scheduling could be improved. The first method a achieved a slight increase in operating ratio and resulted in a savings of 110 flight hours, or 0.98% of the total hours flown for the month. The second method

concentrated on a subset of the mission and achieved a 5.2% reduction in overall hours required to move the same requirements.

Finally, case study of analysis of software developed at Princeton University examines the effects of various scheduling policies on a set of movement requirements. As the simulation introduces cost optimization into the scheduling policy, transportation costs are reduced by approximately 65% and late costs are reduced approximately 60% while improving the throughput of the airlift system.

Abbreviations

AFIT	Air Force Institute of Technology
AMC	Air Mobility Command
AMD	Air Mobility Division
AME	Air Mobility Element
AMWC	Air Mobility Warfare Center
AOR	Area of Responsibility
APOD	Aerial Port of Debarkation
APOE	Aerial Port of Embarkation
C2	Command and Control
COMALF	Commander of Airlift Forces
CONT	Contingency
CDD	Crew Duty Day
DCAMPS	Deployed Consolidated Air Mobility Planning System
DIRMOBFOR	Director of Mobility Forces
DTIC	Defense Technical Information Center
EXER	Exercise
JFACC	Joint Forces Air Component Commander
JMC	Joint Movement Center
OEF	Operation ENDURING FREEDOM
POD	Port of Debarkation
POE	Port of Embarkation
STAR	Standard Theater Airlift Routes
TPFDD	Time Phased Force Deployment Database

TRANSCOM	United States Transportation Command
USA	United States Army
USAF	United States Air Force
USCENTCOM	United States Central Command
USEUCOM	United States European Command

Glossary

Command and Control (C2)-The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. (JP 1-02, 2001:80)

Channel Airlift-Common user airlift service provided on a scheduled basis between two points. There are two types of channel airlift. A requirements channel serves two or more points on a scheduled basis depending upon the volume of traffic; a frequency channel is time-based and serves two or more points at regular intervals. (JP 1-02, 2001:65)

Director of Mobility Forces (DIRMOBFOR)-Normally a senior officer who is familiar with the area of responsibility or joint operations area and possesses an extensive background in airlift operations. (JP 1-02, 2001:128)

Forward Operating Base (FOB)-An airfield used to support tactical operations without establishing full support facilities. The base may be used for an extended time period. (JP 1-02, 2001:169)

Theater airlift-That airlift assigned or attached to a combatant commander other than Commander in Chief, US Transportation Command, that provides air movement and delivery of personnel and equipment directly into objective areas through air landing, airdrop, extraction, or other delivery techniques; and the air logistic support of all theater forces, including those engaged in combat operations, to meet specific theater objectives and requirements. (JP 1-02, 2001:429)

Theater distribution-The flow of personnel, equipment, and materiel within theater to meet the geographic combatant commander's missions. (JP 1-02, 2001:430)

Theater distribution management-The function of optimizing the distribution networks to achieve the effective and efficient flow of personnel, equipment, and materiel to meet the combatant commander's requirements. (JP 1-02, 2001:430)

Time-Phased Force and Deployment Data (TPFDD)-The Joint Operation Planning and Execution System database portion of an operation plan; it contains time-phased force data, non-unit-related cargo and personnel data, and movement data for the operation plan, including the following; a. In-place units; b. Units to be deployed to support the operation plan with a priority indicating the desired sequence for their arrival at the port of debarkation; c. Routing of forces to be deployed; d. Movement data associated with deploying forces; e. Estimates of non-unit-related cargo and personnel movements to be conducted concurrently with the deployment of forces; and f. Estimate of transportation requirements that must be fulfilled by common-user lift resources as well as those requirements that can be fulfilled by assigned or attached transportation resources. (JP 1-02, 2001:432)

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14. ABSTRACT

Air Mobility Command provides rapid, global mobility and sustainment for US armed forces and plays a crucial role in humanitarian support operations around the world. Since customer requests for airlift resources to support these missions almost always exceed the supply, effective and efficient scheduling of these resources is critical.

This research explores the similarity between Air Mobility Command airlift scheduling and US motor carrier industry scheduling with respect to improving efficiency. It begins with an overview of Air Mobility Command's organization and functional relationships with regard to scheduling of airlift assets and a review of currently fielded airlift modeling and simulation systems. This is followed by a review of the US motor carrier industry with an emphasis on scheduling and efforts to improve efficiency in that industry as well as the results.

After reviewing practices employed by the motor carrier industry to improve efficiency, similar methodology is applied to a set of historical airlift missions to measure and attempt to improve the scheduled efficiency of these missions. A measure of efficiency, the operating ratio, is developed through analysis of Air Mobility Command mission numbers. Finally, case study analysis is presented of computer simulated scheduling utilizing various optimized scheduling policies.

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